A FEW OBSERVATIONS ON THE GEOLOGY AND GEOGRAPHY OF NORTH-WEST AND DESERT BASINS, WESTERN AUSTRALIA.

By Frederick G. Clapp.*

(*Communicated by Professor Sir T. W. Edgeworth David.*)

(Plates xvi-xix and five Text-figures.)

[Read 29th April, 1925.]

Introduction.

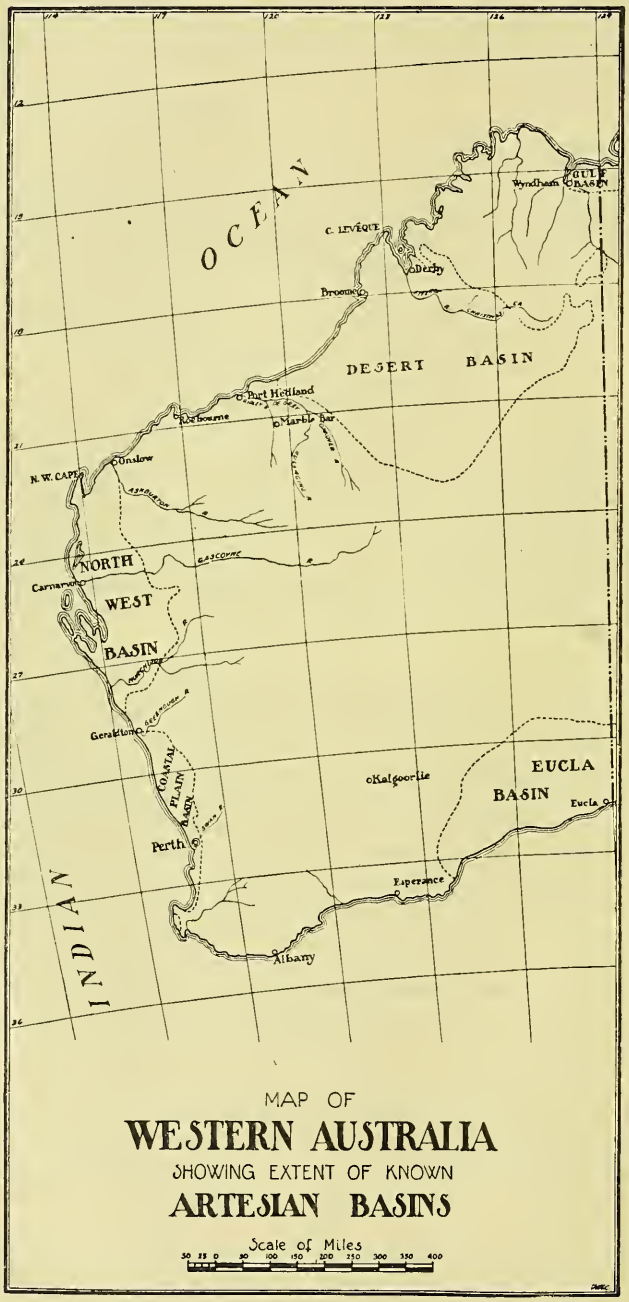
During seven months of the year 1924 I had an opportunity of making nearly 6,000 miles of geological traverses in northwest Western Australia, and in so doing I visited some localities that had never been studied geologically and others that had been but little studied. In the absence of sufficient time to prepare a detailed account of geological and geographical conditions in the country traversed, some outstanding features are presented herewith for the information of future investigators.

The study does not pretend to be a finished one in any sense, except insofar as it was carried to a logical conclusion in connection with certain areas under option to my client for the purpose of determining certain economic conditions. Time was so much a factor that I even found it necessary to pass entirely, or to make extremely hasty visits to important geological localities in the vicinity of traverses, for business reasons, and to omit entirely certain other localities which, from the viewpoint of pure geology, would have been considered essential to a solution of the problems outlined in this paper. If my discussions appear one-sided, if they are devoted to certain areas in contradistinction to others of greater geological importance, or if some hypotheses advanced are later found untenable, I hope, at any rate, that the information may prove helpful. The country is a vast one and little known, the Government Geological Survey is handicapped by insufficient funds, and the duty of a geologist is obviously to help the cause of science by placing on record any information at his disposal.

The country investigated covers in a general way the greater part of what are known as Desert Basin and Northwest Basin (Fig. 1),† both of which consist predominantly of Permo-Carboniferous strata (Figs. 2 and 3). My routes of necessity traversed rocks of this age and also overlying sediments as well as older systems on the borders of the two Basins. Vast areas were never visited, but

* Published with the permission of Mr. A. E. Broué, of 11 Castlereagh Street, Sydney, N.S.W., for whom the investigations in Western Australia were undertaken.

† Fig. 1, representing the positions of the basins, was taken from an old map and has not been corrected to include new discoveries in outline of Desert Basin, such as are described in this paper.



Text-fig. 1.—General map of Western Australia, showing relative positions of Desert Basin and Northwest Basin.

available information supplied by other geologists has been freely used. Desert Basin covers a large portion of Kimberley, Northwest and Eastern Divisions of Western Australia, whereas Northwest Basin is situated entirely in Northwest Division. This paper should be read together with frequent reference to the geological map of Western Australia, published as Plate I in Chapter I of The Mining Handbook, Memoir No. 1 (1919), by Mr. A. Gibb Maitland.

Outline of physical features.

The topographical features of Western Australia have been previously classified into (1) Coastal Plain, (2) Hill Ranges and (3) Interior Plateau. In the country traversed, the width of Coastal Plain is nil in places between Port Hedland and Onslow, but expands to 100 miles or more in Gascoyne District of Northwest Division. Between Broome and Wollal in Desert Basin, this plain merges with the Interior Plateau so gradually that no boundary can be pointed out, and the Hill Ranges are missing.

In order to maintain a consistent basis of discussion, the Coastal Plain is here considered as being practically synonymous with the area of Tertiary age; nevertheless such anomalies exist as "Cape Range," west of Exmouth Gulf (Fig. 4 and Plate xvii, fig. 2), which is of Tertiary age and over 1,000 feet high, although no other land east of Hill Ranges has an equal height. Another inconsistency in the above mentioned synonym is that, in Gascoyne and Lyndon Districts of Northwest Division, much of the country that is topographically Coastal Plain is of Jurassic age.

Such Ranges as Kennedy, Carrandibby and others (Fig. 3) in Northwest Basin, and Dampier and Edgar Ranges in Kimberley are topographically part of the Interior Plateau and are of Permo-Carboniferous age. My observations lead to the opinion that the term "Great Plateau" or "Interior Plateau" should be used with discrimination, for, in both basins, it merges on the west with the Coastal Plain; and even over 100 miles in the interior, midway between Dampier Range and De Grey River, I have found the so-called "plateau" to be only 300 feet above sea-level (barometrically).

General remarks on the geology.

Although geological work in this portion of the State is in its infancy, many valuable reconnaissances have been made, and all explorers have contributed to present knowledge. Mr. E. T. Hardman, pioneer observer and one-time Government Geologist, conducted explorations in 1883 and 1884,* on which subsequent mapping has been based; and his mapping is accepted in areas in which my observations overlapped his. The work of Messrs. Gibb Maitland and Talbot of the present geological survey has been of tremendous value, as have reports made by other men† in the employ of the Government; and certain private investigators, whose work has not been published and whose names I am not at

* Hardman, Edward T.: Report on the geology of the Kimberley District, Western Australia; published by the Government Printer, Perth, 1884, pp. 1-22, with 16 plates; also geological map published separately.

† Woodward, H. P.: Geological sketch map showing the possible artesian water area between the Minilya and Ashburton Rivs., 1907 (in two sheets); and others.

liberty in all cases to mention, have given valuable information* as to conditions in portions not personally visited. Other publications, by Talbot, Jack and others, a valuable paper on the physiography of Australia by Prof. Griffith Taylor and a report by Gibb Maitland in the Proceedings of the Third Interstate Conference on Artesian Waters have been considered, but the references are not quoted, as the records are not now accessible to me.

Nearly all of my work lay in the Northwest and Desert Basins, and the economic problems were limited to those basins; therefore I will refrain from discussion of observations outside them, except such as bear on the Basin problems. Explorations were limited to areas of Recent, Quaternary, Tertiary and Permo-Carboniferous sediments, overlapping in a few instances into granitic areas of unknown age, Nullagine and Pre-Cambrian sediments and metamorphics. The essential characteristics of these formations have appeared in an excellent summary by Gibb Maitland.†

General Similarity of Northwest and Desert Basins.

One might suppose that Northwest and Desert Basins have few characteristics in common. For instance, they are separated by a belt of Pre-Cambrian rocks 350 miles wide where narrowest and which rise in places to over 4,000 feet above sea-level. Desert Basin is roughly quadrilateral in shape, with its longer diameter approximately at right angles to the coast; whereas Northwest Basin, like the "Coastal Plain Basin" farther south, constitutes a belt nowhere more than 150 miles wide, parallel to the coast from Onslow to Murchison River. Desert Basin is roughly 325 miles in a northeast-southwest direction by over 450 miles northwest-southeast. On the other hand, Northwest Basin extends 400 miles north and south by 75 to 150 miles east and west.

A popular conception of Desert Basin is that it constitutes a desert, as the name implies. As a matter of fact, large areas of Desert Basin are so barren and sandy as to have practically a desert charcter, whereas the greater part of Northwest Basin is prosperous pastoral country, in which two score artesian wells have been sunk, yielding some of the greatest flows in the Commonwealth and proving an area of perhaps 15,000 square miles to have artesian possibilities.

It must be remarked by anyone who glances at the geological map of the State, that the principal stratigraphical divisions (Tertiary, Jurassic, and Carboniferous) in the two Basins are identical. Furthermore, the details of stratigraphy throughout portions of the basins examined by me are so closely identical as to leave no doubt that the basins were once connected, either across the intervening 350-mile wide Pre-Cambrian and Nullagine Plateau or through Indian Ocean around the north end of this Plateau. In both Basins the Permo-Carboniferous system has been sub-divided into (1) "an Upper or Sandstone group," made up almost entirely of sandstones and analogous porous sediments, and (2) "a Lower or Marine group" (in which limestones appear to predominate). The limestones are interlaminated with sandstones, shaly sandstones, and thin shales.

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* Among these are unpublished reports by T. A. Blatchford, dated 20 Dec., 1923, by H. W. Talbot dated 19 Nov., 1923, by D. J. Mahony (undated), by Leo J. Jones and E. De Villa.

† Gibb Maitland, A.: A summary of the geology of Western Australia. *The Mining Handbook, Geol. Survey Memoir* No. 1, Chapter I, 1919, pp. 7-55, 80 figs. and geological map.

North escarpment of the Interior Plateau in Desert Basin.

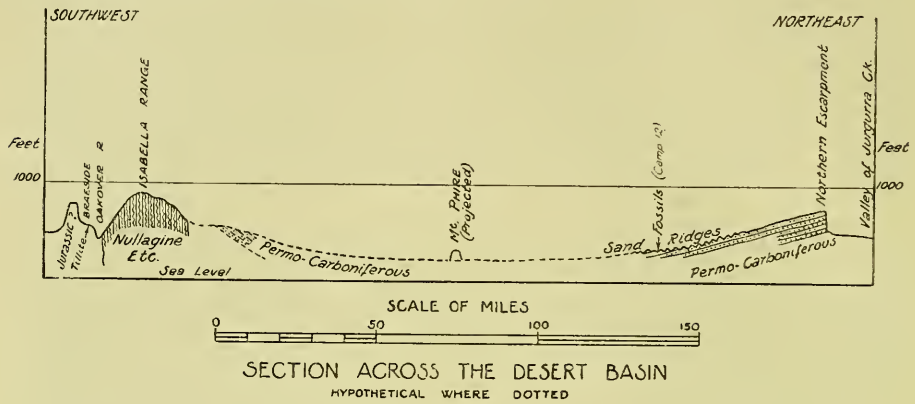
The north escarpment of the Interior Plateau constitutes a vast geographical feature. Commencing 77 miles southeast of Broome, or 35 miles southeast of Hamilton's well, the escarpment first appears merely as a breaking away of the coastal type of country, known as "pindan sands," which extend to that point from the inner edge of the "sea-level plains" near Broome. The pindan sands, covered with a thick growth of many varieties of trees and shrubs, rise from sea-level to a height of perhaps 200 feet at Hamilton's well and to about 700 feet at the "breakaways" mentioned. A few low hills in the vicinity rise a few rods higher; hence the name "ranges" by which they are generally known. Some person more or less familiar with that part of the country has suggested the name "Dampier Ranges" to distinguish them from Edgar Ranges, situated farther east in the vicinity of Jurgurra (popularly called "Jeegully") Creek, which I did not have an opportunity of visiting.

The claim of the height of land along the north escarpment of the plateau to the designation "ranges" consists, firstly, in a slight steepening of the northeastward rise of the Plateau along the line where the Desert sandstones rise from beneath the plains of the west and south, and secondly, in erosional dissection of the sandstone itself, where it drops abruptly 100 to 300 feet into "breakaways" tributary to a broad valley, which thence descends slightly northward and constitutes part of the Fitzroy lowland. A generalized section across Desert Basin is shown in Fig. 2, from which the formations are seen to dip southwest at an angle of 1 to 2 degrees; hence the escarpment is typical of those the world over on up-dip flanks of structures exposed in high-lying sandstones. Calculations based on observed dips in the escarpment and those on the coast and in Mt. Phire (see below) lead me to the opinion that the strata of the escarpment and higher beds may have a total thickness of as much as 10,000 feet.

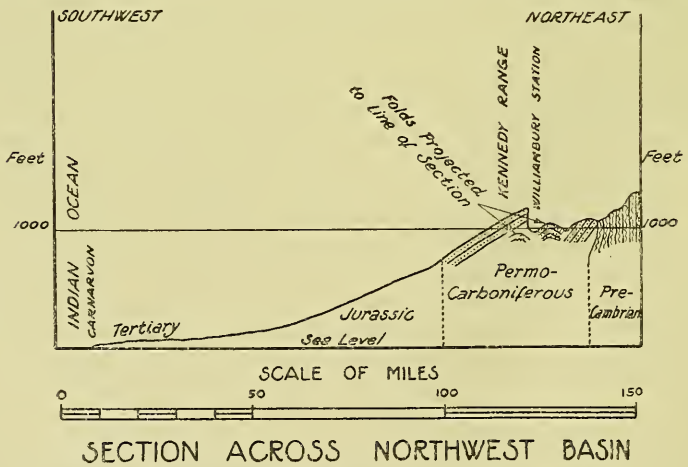
Whereas the valley north-east of the escarpment, at the place, 77 miles southeast from Broome, where touched by my motor road from Broome to Camp 12, can be reached by an easy grade of not over 100 feet per mile, and whereas the crest of the Plateau is accessible on its west side by an even more imperceptible grade, the valley descends eastward and the "ranges" or Plateau crest rises somewhat southeastward, so that within a mile of the northwest termination of the escarpment it becomes nearly 100 feet high and a few miles farther southeast it is precipitous to a height of 200 feet or more. Many isolated tablelands with flat tops, a few acres up to several hundred acres in extent, stand in this valley, and are only higher than the main Plateau by an amount equal to the normal rise in dip toward the northeast (a few rods per mile). Maps of the Lands Department show several of these outliers—named Goorda Tower, Babrongan Tower, Mt. Alexander, Mt. Jarlemai, etc.—far to the northeast, and some of these were visible in the distance from points visited on the north edge of the escarpment.

The rocks of the north Plateau escarpment are fine-grained white sandstones, somewhat aluminous, but never calcareous or even approaching the consistency of shale. In places they contain numerous ferruginous concretions. The dip is southwest and ranges from nothing up to 2 degrees. In a few localities, as at the head of a deep "'breakaway" at Camp 9, 130 miles southeast of Broome, areas were seen up to 3 miles in length and a few hundred feet wide composed of a hard, light gray to white quartzite capping the Plateau a short distance back from the escarpment. It is only a few feet thick and takes the place of limonitic laterite which is an almost constant feature of any sandstone outcrop in the semi-desert

areas. Quartzite is frequently only a vitrified phase of the surface-hardened sandstones and is common throughout Australia in rocks of all ages. From aerial observers and other sources I have received reports of a great ledge of gray quartzite that extends from a point on the Broome-Derby road some 60 miles northeast of Broome north to near Cape Leveque, and this last-mentioned quartzite may constitute part of the same series of rocks.



Text-fig. 2.—Generalized cross section of Desert Basin from Jurgurra Creek to Oakover River.



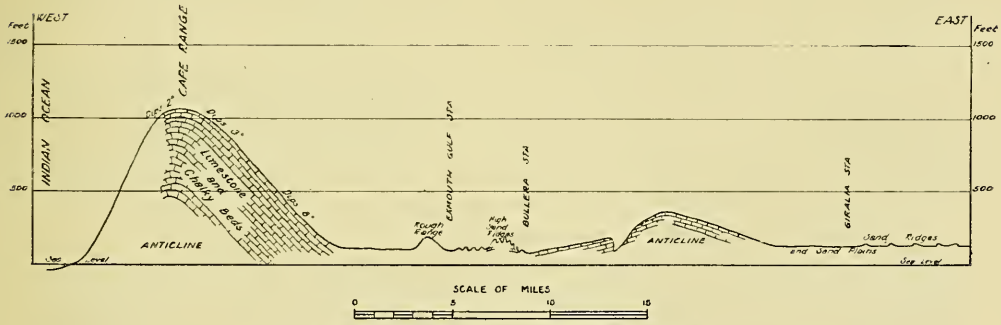
Text-fig. 3.—Generalized cross section of Northwest Basin from Williambury Station to Carnarvon.

In contour the escarpment is not simple, but extends south-east for many miles from its north extremity, and then bends east, forming an irregular line of cliffs throughout—vertical and inaccessible to a vehicle at any point, rarely scalable by man, and the crest of which is accessible to horses only at points dozens of miles apart. From information at hand, the line of cliffs appears to extend east over 200 miles, and it may merge with certain tablelands described by Talbot and others in the vicinity of Canning Stock Route. The "breakaways" in the vicinity of the 123rd meridian indent the Plateau in places for many miles back

of the escarpment proper. Curiously enough, all rock holes that contained water at the time of my visit are situated at the head of "breakaways," except in a few instances where found in canyon-like gorges near the base of cliffs. No water holes, and only a few "native soaks," were found south of the escarpment, and very few natives live in that part of the Plateau.

East escarpment of Kennedy Range.

A comparison of Figs. 2 and 3 will show how similar are the formations and conditions in the escarpment described above to those existing in that of the east edge of Kennedy Range in Gascoyne District of Northwest Division. As in the case of Kimberley, so in that of Gascoyne, the escarpment rises vertically 200 to 300 feet, and apparently can not be ascended by vehicle or animal at any place from its south end, near Gascoyne River, to a point on Merlingleigh Station, a distance of about 50 miles. Even farther north, the cliffs are intermittently abrupt and precipitous for many miles. North and south from Kennedy Range its topographical features are repeated at intervals, represented by a smaller range directly south of Gascoyne River, by Carrandibby Range, 50 miles south, and probably also by Moogooloo Range, north of Minilya River; so that, for over a distance of 150 miles, the escarpment feature is prominent in some degree for intermittent, but long, distances.



SECTION NEAR EXMOUTH GULF

(FROM INDIAN OCEAN ACROSS CAPE RANGE SOUTH 75° EAST TOWARDS WINNING POOL)

Text-fig. 4.—Cross section in vicinity of Exmouth Gulf, showing Tertiary folding.

As with the north Plateau escarpment, so with that of Kennedy Range, the strata consist of fine-grained, white, non-calcareous sandstones, which dip west at angles of less than 5 degrees with only slight reversals (no reverse dip of more than a fraction of a degree for a short distance being visible in the face of Kennedy Range). As with the north Plateau, so with Kennedy Range, the land descends gradually westward from an altitude of approximately 1,000 feet (Plate xix, fig. 1), directly on the escarpment, to the Coastal Plain several hundred feet lower. Somewhere between the west base of Kennedy Range and Indian Ocean, the Permo-Carboniferous rocks pass beneath the Jurassics, which in turn pass beneath Tertiary sediments to the west.

Significance of certain fossil collections.

A point that needs further field attention is the abundant occurrence of large pectenoid valves and others resembling *Productus* in ferruginous conglomeratic

sandstones of hematitic hardness in the semi-desert area about 185 miles, by my tractor road, southeast of Broome (Fig. 2), estimated only a few miles west of McLarty Hills as mapped. This fossil locality lies between 83rd and 87th sand-ridges, counting from the north, and not far from my Camp 12. No outcrops exist between here and the north Plateau escarpment, but those mentioned are plentiful throughout an area of several square miles at an elevation of about 300 feet above sea-level. The fossils are reported by Mr. W. S. Dun to be not definitely determinable, but of probable Permo-Carboniferous age. The outcrops are covered with dark red glaze that takes the place of ordinary laterite in dry arid regions in which the rocks contain much ferruginous matter, and here they are as hard as many regionally metamorphic rocks, although vitrification is due to atmospheric and not to tectonic agencies.

Similar glazing to that which is so prominent near Camp 12 is observable in King's Peaks (two ferruginous sandstone hills about 100 feet high) on the coast roughly 60 miles north of Broome, between King's Peaks and Pender Bay, and in the country between Lagrange and Anna Plains Station back of Ninety Mile Beach. In the last-mentioned locality, one fossil species was found by Mr. B. E. Bardwell and presented to me, but its identity has not been determined. Glazing of the same type is reported by Mr. Gibb Maitland in similar rocks, from an altitude of 1,200 feet above sea-level at Trig. Station K37, on top of the south end of Kennedy Range, just north of Gascoyne River, where he collected unnamed species of *Spirifera*, *Productus*, *Athyris* (?) and *Strophalosia*.

Since outcrops of similar character overlie the Desert Sandstone escarpment in the north and occupy a similar position on Kennedy Range, the results of the determination of the species collected near Camp 12 (if determinable at all) are awaited with interest, to learn whether any further evidence is afforded of the continuity of sedimentation from one Basin to the other, either across the intervening Plateau or through a submarine connection.

Although not necessary for a consideration of any particular problem discussed herein, a publication of the names of identified Permo-Carboniferous species collected on the recent expedition, and determined by Mr. Dun, may be of value. The determinations were made through the agency of Prof. Sir T. W. Edgeworth David and the courtesy of Mr. E. C. Andrews, Government Geologist of New South Wales. The localities are believed to be arranged in stratigraphical order from below upwards (from 1 to 5), but this order is by no means certain. All of the species are believed to be from the so-called "Lower or Limestone series" of the Permo-Carboniferous.

List of identified species of Permo-Carboniferous fossils collected on the expedition to Western Australia.

(Determinations by Mr. W. S. Dun.)

1. From a persistent earthy crinoidal limestone outcropping 6 miles northwest of Lyons River Homestead, between Lyons River and Kennedy Range on road from Lyons River Homestead to Mt. Sandiman Station shearing-shed.

Amplexus pustulosus Hudl.
Crinoid stem ossicles.
Fenestella, sp. undescribed.
Phyllopora, sp. undescribed.
Stenopora, 2 species.
Spirifera marcoui Waagen (sp. by Etheridge, Jr.).
Spirifera musakheylensis (Eth., Jr., not Davidson).

List of identified species of Permo-Carboniferous fossils collected on the expedition to Western Australia—continued.

Spirifera cf. lata McCoy.
Spiriferella australasica Etheridge, Jr.
Cleiothyris macleayana Etheridge, Jr.
Chonetes pratti Davidson.
Productus spines.
Pleurophyllum sp.
Monilopora nicholsoni, Etheridge, Jr.

2. From limestones lying a few feet above Lyons conglomerate, 28 miles southeast of Gascoyne Junction, on road to Dairy Creek Station.
Chonetes pratti Davidson.
Productus, sp. nov. (will be named *P. clarkei*).
Spirifera, sp. undetermined (*musakheylensis* ?).
Spirifera, cf. *marcoui* Waagen.

3. Believed to be from same locality as No. 2 above.
Stenopora, dendroid.
Fenestella, 2 species.
Aulosteges baracoodlensis.
Productus, sp. nov. (will be named *P. clarkei*).
Athyrid (*Cleiothyris macleayana* ?).

4. From flaggy sandstones, 5 miles west of Gascoyne Junction, on road to Carnarvon.
Productus pellus.
Spirifera cf. *lata* (Etheridge and Foord, not McCoy; will be renamed *maitlandi*).
Pleurophyllum australe Hinde.
Chonetes sp. (*pratti* ?).

5. From well, 5 miles northeast of Merlingleigh Station (temporary camp) and east of Kennedy Range.
Spirifera lata Foord, not McCoy.
Spirifera cf. *musakheylensis*.
Chonetes pratti Davidson.

6. From Merlingleigh Station, well, at temporary camp at foot of east side of Kennedy Range.
Spirifera cf. *musakheylensis*.
Spirifera marcoui.

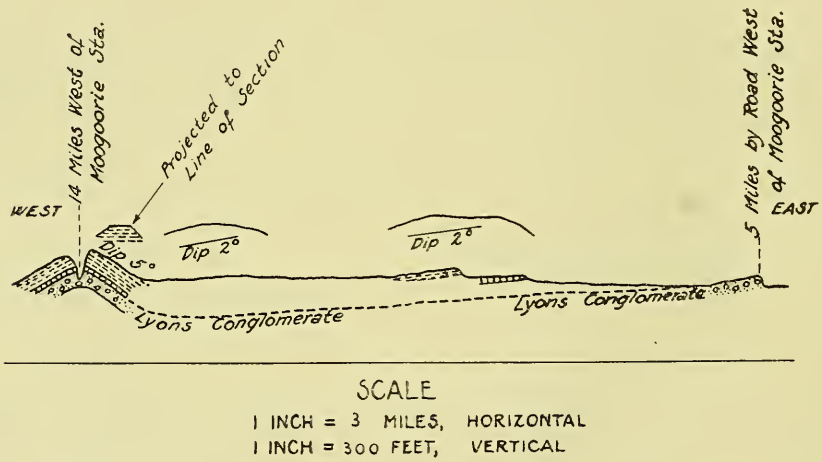
A comparison of the strata in the east escarpment of Kennedy Range with those in the north escarpment of Desert Basin is interesting. In both instances the rock is essentially a fine-grained white or very light gray, frequently soft, porous rock, mainly siliceous to chalk-like, with no ascertainable calcareous admixture. The rock is finely stratified and contains numerous ferruginous and cherty concretions parallel to the bedding. Both the Desert Basin formations and those of Northwest Basin are overlain sea-ward by strata of supposedly Jurassic age, often having similar characteristics to the Permo-Carboniferous and not to be differentiated on lithologic evidence alone.

Structure of beds underlying Plateau beds.

The Permo-Carboniferous age of the two Plateaus, as well as that of outcrops for many miles east and north respectively, has been proven, by Gibb Maitland, on fossil evidence alone. No unconformity has been reported in the series. Nevertheless, the discordance in character and structure of the sub-plateau beds from those constituting the Plateaus is so striking, both in Northwest and in Desert Basins, that, in my opinion, the possibility of the existence of a mid-Permian unconformity should be suggested and tested by exhaustive field examination.

In numerous outcrops examined from Gascoyne Junction, east of Kennedy Range, north to Williambury Station (roughly 85 miles), and southeast to Dairy

Creek Station (50 miles), the rocks dip occasionally in directions opposed to normal, and in places they dip as much as 8 degrees toward the east. In travelling over the motor road from Gascoyne Junction to Dairy Creek Homestead an anticlinal axis is crossed where, a few miles west of that homestead, abnormal and reverse dips cover a breadth of several miles. A similar fold was seen on north side of Gascoyne River between Arthur and Wyndham Rivers, and may or may not be identical with the axis mentioned. Slight east dips were seen at several points between Kennedy Range and Lyons River, between Lyons and Minilya Rivers and they are reported by Mr. E. De Villa and others on Minilya River (in unpublished manuscript). The best dome was seen in the southwest part of Williambury Station, 14 miles west of Moogoorie Homestead (Fig. 5 and Plate xix, fig. 3). This locality is situated 9 miles from the normal outcrop of Lyons conglomerate; yet this is domed upward, together with its overlying sandstones, projecting above the normal surface in a central valley almost entirely surrounded by outcrops, dipping outwards and consisting largely of cliffs up to 50 feet in height.



Text-fig. 5.—Cross section of doming at point on Williambury Station, at north end of Kennedy Range.

Probable Permo-Carboniferous of Dampier Land.

Although the western edge of the peninsula (once known as Dampier Land) west of King Sound is Jurassic, as mapped, I am under the impression that the balance of the peninsula may be largely of similar age to the Plateau escarpment, which is believed to be Permo-Carboniferous. One geological observer is convinced he saw folds in a sandstone north of Wanganut well, on the road from Broome to Beagle Bay Mission. My own impression is that the beds at the particular point are of duller shades than the Plateau beds of the coast and west of Wanganut well, and their elevation of several hundred feet gives the impression that they may constitute a fold against which Jurassic sediments were deposited to the west and south-west. The coarse ferruginous conglomeratic sandstones of King's Peaks (some 60 miles north of Broome on the coast), between Carnot and Beagle Bays,

with their peculiar glaze and hematitic veining, suggest the beds that have been called Permo-Carboniferous near Camp 12 and back of Ninety Mile Beach. Similar hard coarse ferruginous rocks extend near the coast from King's Peaks to Beagle and Pender Bays, but no fossils could be found in them.

Remarks on Lyons conglomerate.

The Lyons conglomerate (Plate xix, fig. 2) is one of the most interesting formations in Northwest Basin. It has been so fully described (Gibb Maitland, *op. cit.*, pp. 34-35) that I need only remark that it is an immense boulder bed—an actual tillite—composed of innumerable ice-scratched pebbles and boulders and having other essential phenomena, extending from Lyndon River, with some interruptions, south for a distance of 400 miles; and its actual outcrop can be traced in Lyndon and Gascoyne Districts for about 200 miles.

In considering the similarity of stratigraphic conditions in the two Basins it may be well to remark that Talbot and others have found a boulder bed in the Fitzroy Valley in the north part of Desert Basin at about the same stratigraphical position, and that a previously unknown tillite locality was recently discovered by myself at Braeside Station, south of Desert Basin.

An interesting feature of the Lyons conglomerate is its presence in the centre of an almost perfect dome, some 9 miles west of its normal outcrop, at a point on Williambury Station, 14 miles west of Moogoorie Homestead and a short distance south of Minilya River. The east side of this dome is shown in Plate xix, fig. 3 and a cross section of the locality appears in Fig. 5.

Other Conglomerates of probable Permo-Carboniferous age.

On Moogoorie Station, intermediate between Minilya and Lyons Rivers, certain conspicuous outcrops of hard, coarse, quartzitic conglomerate occur below the "limestone series" and are almost certainly of Carboniferous or Permo-Carboniferous age. Similar conglomerate, resting on granite, is described by Gibb Maitland (*loc. cit.*, p. 36) at Warrie well, on Towera Station on Yannerie River. Similar outcrops were also seen by me on Pardu Station, near the southwest corner of Desert Basin, and there seems no reason for supposing their age to be other than Permo-Carboniferous, although they might conceivably be Jurassic. The Pardu conglomerates are very ferruginous over many square miles, but an occasional white, unoxidized exposure classes them with a vast succession of white siliceous rocks of varying texture. They bring the known rocks of Desert Basin to within 50 miles of De Grey River or 40 miles farther southwest than reported on the published geological map. The contiguous area of granite is found to be narrower than mapped near the coast, but 100 to 150 miles southeast it is much wider than mapped, even including some of the area mapped as Carboniferous east of Paterson Range.

Features in common to both Basins.

Summarizing the evidence given, it appears that the north escarpment of the interior Plateau in southern Kimberley Division is similar, geologically and geographically, to that bounding the east face of Kennedy and Carrandibby Ranges in Gascoyne and Lyndon Districts of Northwest Division in the following respects:

1. In its height of 100 to 300 feet, either continuously (as in Desert Basin) or throughout intermittent stretches of 20 to 50 miles each, separated by low-lying areas (as in Northwest Basin).

2. In a characteristic whiteness of the escarpment, i.e., in its texture of generally fine (but locally coarse) non-calcareous sandstone.

3. In the fact that both Plateaus are surmounted by sand-dunes, situated on the Plateau edge in part (in Kennedy Range), but 30 miles or more back from the escarpment elsewhere (in Desert Basin).

4. In a characteristic vegetation of spinifex, interspersed with shrubs and low trees, interrupted by sandy patches, but commonly having suitable feed for cattle or sheep.

5. In a continuous dip of the strata from the escarpment into the Plateau, until the latter merges with the low plain to the south or east respectively.

6. In the occurrence of small springs of fresh water on the down-dip side of the "ranges." The only genuine springs of which I know, in the western part of Desert Basin, are situated 45 miles east of Anna Plains Homestead and have been rarely visited; and in Northwest Basin many springs emerge along the west side of Kennedy Range. An interesting fact is that only saline waters are commonly found in bore holes 50 to 100 feet deep on the low plain directly east of the Kennedy and Carrandibby Range escarpments and that saline springs flow continuously from a few spots on that side of the ranges and directly north of Gascoyne River. That is, fresh water exists in outcropping strata on the down-dip side of Kennedy Range and saline water on its up-dip side. A "salt marsh" is reported by the Lands Department over a practically sea-level plain, situated, roughly, 35 miles southeast of Anna Plains Homestead in Desert Basin; and wells sunk on sea-level plains between Edgar and Pardu Stations (back of Cape Villaret and Ninety Mile Beach respectively) are frequently saline, but this salinity is attributed to another cause than those pertaining to wells in Permo-Carboniferous strata.

7. The beds of both escarpments are flat or have a dip of less than 5 degrees, and they generally dip only 1 or 2 degrees in the direction of normal dip; in contrast to lower rocks of the country east of Kennedy Range escarpment and north of Desert Basin escarpment, where dips of 5 degrees and upwards are common and reverse (east and north, respectively) dips are not unknown. Only in one or two instances are reverse dips (those contrary to the direction of normal dip) found in either escarpment; but reverse dips of as much as 10 degrees have been seen in some instances, and those of over 1 degree in many instances, in the lower beds east of the escarpment in Gascoyne and Lyndon Districts of Northwest Basin. Reverse dips of greater angle are reported in Fitzroy Valley by Messrs. Talbot and Blatchford in unpublished private reports, and by other geologists in informal verbal communications.

8. The characteristic colour of the beds in the escarpments is white (except where ferruginous beds have been reddened owing to oxidation), whereas the lower series of sandstones and limestones appears to be almost any shade of gray, but seldom white throughout any considerable thickness.

9. No limestones or shales are known in either escarpment, but thin shales and great thicknesses of limestone, as well as of sandstone, abound in the lower land to the east (in Northwest Basin) and north (in Desert Basin).

10. Instead of being uniformly devoid of fossils, like the sandy escarpment beds throughout hundreds of feet vertically, the lower calcareous strata abound with fossils.

Distribution of Jurassic strata.

On the published geological map, an area of Jurassic rocks is represented in western Desert Basin. It includes a small patch near Derby, nearly the whole of the peninsula west of King Sound, and a belt along the coast that has a diminishing breadth of from 40 miles near Broome to nothing at Wollal. In Northwest Division the Jurassic system consists of a belt of variable width extending south from Onslow, across Lyndon and Gascoyne Districts to beyond Wooramel River—the approximate southern limit of the area studied. I have no definite suggestions for additions or corrections to the map, so far as Northwest Basin is concerned; although I have an impression that a narrow belt of Permo-Carboniferous rocks may possibly be traceable from Yannerie River (the farthest point north at which it has been reported and mapped) to Ashburton River and thence somewhat east of that river to the coast.

In Desert Basin some suggestions may be of value. As stated by Gibb Maitland (op. cit., p. 41), Jurassic rocks "'may extend some distance into the Interior" east of Ninety Mile Beach. The Jurassics are not continuous, evidenced by the discovery of probable Permo-Carboniferous fossils in the characteristic glazed red conglomeratic sandstone on Anna Plains Station, the frequent occurrence of this rock north to beyond Lagrange, and the discovery of abundant Permo-Carboniferous (?) fossils in similar rock near Camp 12, west of McLarty Hills, as described in this paper.

The identification of Jurassic strata in western Desert Basin is largely dependent on the discovery by Gibb Maitland (*loc. cit.*) of *Belemnites* 1,300 feet below the surface in bore No. 2 at Broome. The mapped extensions of Jurassic north and south of Broome are doubtless based largely on the occurrence of certain outcrops—similar to those at Pt. Gantheaume and Entrance Point near Broome—along the coast at widely separated localities, viz., at Cape Borda (according to a verbal report made to me by a geologist who visited it) and Cape Villaret, 25 miles southwest of Broome. The predominant rocks at these localities are fine-grained white sandstones in which small flakes of mica are prominent.

At Pt. Gantheaume, 4½ miles west of Broome (Plate xviii, fig. 2), the outcrops beneath the laterite covering, in cliffs 60 feet high, consist of fine to medium grained, somewhat micaceous sandstone, cross-bedded to regularly bedded, in which the dip averages 1 to 2 degrees in a direction S. 60° W. At Entrance Point, somewhat nearer Broome, in cliffs 30 feet high, the strata are similar, light gray to white, hard to soft, regularly bedded sandstones. At the south end of Cable Beach, 3 miles north of Pt. Gantheaume, underneath laterite deposits, are a few outcrops of white, micaceous, fine to medium grained, regularly bedded sandstone, flat or dipping very slightly southwest. Mica flakes are also abundant in white sandstone thrown out of Hamilton's well, 42 miles southeast of Broome, but the rock in other respects resembles that of the Plateau escarpment.

At Cape Villaret, 25 miles southwest of Broome, the 70 foot cliffs consist in part of Recent consolidated sand-dunes (Plate xvi, fig. 2), but in other portions they are fine-grained, white or oxidized, hard sandstone, with some coarse sandstone layers, some thin bands of which contain mica flakes and some hematitic beds, weathered into fantastic forms and surface hardened as usual (Plate xviii, fig. 1). Coarse, white, unoxidized sandstones are interbedded with the fine-grained beds. The dip averages 1½ degrees in a direction N. 15° W.

Cape Villaret is the last coastal outcrop to the south at which I saw characteristic Jurassic material in Desert Basin; but Mt. Phire, 15 miles east of Anna

Plains Homestead, and 50 miles south of Lagrange, I found to be an unmapped table-top group of five hills (Plate xvi, fig. 3), distributed over 2 square miles, supplemented by an isolated hill 2 miles farther east. These hills are interesting physiographically, being the only known summits north of Callawa Hills (see herein below) that stand above the regular level of the "pindan sands," except an isolated tower-like hill with steep sides visible from Mt. Phire in the far distance and estimated 30 miles N. 35° E. The height of the Mt. Phire group is estimated at 100 to 130 feet above the low plain. The hills are capped by fine-grained white micaceous sandstone and hard semi-porcellanitic material alternating with, or underlain by softer chalky beds. The dip is 1½ degrees in a direction N. 65° W. The upper 10 to 30 feet consists in places of red massive sandstone, resting with very slight unconformity on finer grained beds (Plate xvii, fig. 1).

Owing to the rough regularity in height of table-tops (Pt. Gantheaume, Capes Borda and Villaret, Mt. Phire and the unvisited peak to the northeast), all 70 to 130 feet above other outcrops, and the presence of these rocks lying practically flat within a few miles of the Broome bore in which Jurassic fossils were found, they all appear to be of probable Jurassic age. Other outliers, similar to Mt. Phire and the unvisited peak, may be dotted over the southwest part of Desert Basin, but they are as yet undiscovered.

Probable Jurassic extension south of Desert Basin.

Near the 121st meridian west of Oakover River, stands a persistent tableland that has been traced from near the junction of Oakover and Nullagine Rivers south to Braeside Station and thence seen to extend out of sight far to the southward. Although only a few miles in breadth, it rises from the valleys abruptly 100 to 120 feet, is capped by hard, white, frequently opalescent quartzite, often over 30 feet thick, and generally lies nearly flat.

This tableland is doubtless the one mentioned by Gibb Maitland (op. cit., p. 47) as occurring near Carawine Pool and suspected by him of being Tertiary; but in conversation he admits that its age may be Jurassic, as the evidence seems to be absent. On my traverse south from near the junction of Oakover and Nullagine Rivers, this tableland was paralleled almost continuously, and glimpses of it were also obtained far to the north, where it enters Desert Basin and is apparently continuous with Callawa Hills. The last-mentioned have not been visited by me, but their near continuity and similar topography are worthy of note. A reasonable assumption is that Callawa Hills may be of identical age with Mt. Phire, which is similar topographically; and if this correlation be true, the age of the tableland of the Nullagine-Oakover divide is also probably Jurassic. Whether or not this be so, the tableland of the Nullagine-Oakover divide constitutes an outlier of Desert Basin rocks resting on Nullagine and older rocks south of the Basin proper.

Braeside (tillite) formation.

Less than a mile east of the tableland above described, between it and Oakover River, and situated 2 miles north of Braeside Homestead, more than 100 feet below the tableland and intermediate between it and the valley bottom, I found an unrecorded tillite deposit. It forms gentle slopes throughout an area of perhaps 100 acres and consists of soft, light gray, granular, siliceous and aluminous material capped by a thin bed of harder coarse conglomerate. The white material is filled with erratic pebbles of granite, gneiss, quartz, sandstone, shale, schist, etc.,

but none of the peculiar opalescent quartzite from the tableland to the west was found in it. The pebbles are frequently finely striated, and are in size up to a foot in diameter. Some are rotten, owing to weathering, although the surface of an individual pebble appears very fresh.

My impression is that this tillite is of pre-Jurassic age, reasoning from its topographic position with reference to the tableland, and also from the fact that no pebbles of Jurassic (?) quartzite were found in it. Otherwise it might be supposed equivalent to the Wilkinson Range beds of tillite found by Talbot in Princess Range, near Lake Carnegie, 350 miles south, and provisionally assigned by him to the Cretaceous system.* If the tableland of the Oakover-Nullagine divide be of Tertiary age, as was originally suspected by Gibb Maitland, the Braeside tillite may be of Cretaceous age; otherwise it is probably Permo-Carboniferous, constituting the first discovery of Permo-Carboniferous tillite on the south flank of Desert Basin. The difficulty of accepting a Permo-Carboniferous age lies in its quite different character from the very coarse, relatively dark Lyons conglomerate of Northwest Basin; but, as has been well said, "lithologic character is no criterion for the age of a tillite."

The tablelands and their significance.

The common designation "Great Plateau of Western Australia" seems, to a stranger in the country, to be too generalized and often used loosely. Of course, in ascending the north escarpment in Kimberley Division at any one of many points, and travelling along it or across it for hundreds of miles at never less than 700 feet above sea-level, as has frequently been done farther east, one feels unconsciously that the Plateau is a unit. But, as was learned on the recent trip in travelling south from the escarpment, the plain slopes south from this elevation to roughly 300 feet above sea-level in inter-ridge valleys near the Fiftieth sand-ridge, 40 miles or so south of the escarpment and 170 miles more or less southeast of Broome. The occurrence of supposed Permo-Carboniferous fossils in these valleys 185 miles southeast of Broome and estimated 130 miles eastsoutheast of Anna Plains Station is some index of the age of the beds forming the Plateau; but the fact that Cape Villaret and Mt. Phire rise 70 and 130 feet respectively above the coastal Permo-Carboniferous (?) plain (Plate xvi, fig. 3) establishes them as remnants of a higher Plateau, the beds of which are probably of Jurassic age. It is this last-mentioned Plateau that may once have been continuous with that of Callawa Hills and the tableland of the Oakover-Nullagine divide. The two plateaus—a widespread one composed of Permo-Carboniferous strata and probably Tertiary peneplanation, and a more fragmentary one composed of Jurassic beds—should be carefully differentiated in any consideration of the physiography of northwest Western Australia.

Some facts may seem to warrant the assumption that the sandstones of the north Plateau escarpment, and hence those of the great central portion of Desert Basin, are of Jurassic age, instead of Permo-Carboniferous; but Mr. Dun's opinion that the fossils from Camp 12, 185 miles southeast from Broome, are probably Permo-Carboniferous, does not substantiate this view; hence we can continue to consider the north Plateau escarpment and the centre of Desert Basin to be Permo-Carboniferous as mapped.

* Talbot, H. W. B.: *Geol. Survey W. Aust.*, Bull. 83, 1920, pp. 59-60, fig. 16 and frontispiece.

Turning now to Northwest Basin, there is positive evidence (in the form of fossils collected by Gibb Maitland from Trig. Station K37, on top of the south end of Kennedy Range) that this range, together with Carrandibby and Moogooloo Ranges, is of Permo-Carboniferous age; and, since these hills have roughly an altitude of 1,000 feet above sea-level, they should be considered contemporaneous with the north Plateau escarpment.

Near Winning Pool, southeast of Exmouth Gulf, some white, chalk-like hills, 50 to 100 feet high, have an east-facing escarpment and are mapped as Jurassic. These perhaps may be correlated with the outliers of supposed Jurassic age in western and southern Desert Basin; although in character they resemble the north Plateau escarpment and some beds in a ravine west of Wanganut well between Broome and Beagle Bay (southwest of the outcrops described hereinabove as Permo-Carboniferous). Higher outliers a few miles southeast of Winning Pool have not been visited. Far to the west of Winning Pool, on Giralia and Bullera and west of Exmouth Gulf, widespread folding of probable Tertiary age has occurred, so that Tertiary sediments are much higher in elevation than are any of the tablelands mentioned.

Distribution of Tertiary and Post-Tertiary strata.

The Tertiary strata of Northwest and Kimberley Divisions have received little attention. Some of the outcrops of low-lying limestones and calcareous sandstones along the coast are undoubtedly Quaternary and Recent. Careful study of the narrow coastal belt mapped as Tertiary and Post-Tertiary between Roeburne and Broome might lead to interesting differentiations. My own observations include the following:

1. Unconsolidated sand-dunes and sand-ridges.—These are the most recent formation in Western Australia and are still being deposited, not only on the coast (Plate xvi, fig. 1) but also over large areas in the interior. In my traverse south from the north Plateau escarpment, eighty-five of these sand-ridges were crossed, each one constituting an entity, very persistent, and few of them having any ascertained termination. Their trend varies with few exceptions between S. 75° W. and N. 75° W.; they range from a few feet to 60 feet in height, measured from the base of sharp ascent, but are much higher if referred to the centre of the inter-ridge valleys. The width of the ridges varies from 150 to 1,500 feet, and they are often composite, rough and hilly, with several crests. Most of them are covered with a growth of hummocky spinifex, but they have a greater proportion of sand than spinifex surface, and they support a few trees, as do also the valleys between them.

The most interesting features of these sand-ridges are their great persistence, regularity of trend, and the fact that the valleys between them are only slightly encumbered with deep sand, so that an ordinary motor car, once arrived between any two of the ridges, could travel for long distances between them, by jolting over the spinifex clumps that are rarely absent from any square rod of surface. Little possibility exists of a motor car crossing these sand-ridges without special appliances for the wheels, which sink deep into the sand, but caterpillar tractors can cross them if well supplied with petrol, water and spare parts.

The sand-ridges are not only present in the interior of the Plateau, but they strike the coast throughout a belt roughly 70 miles wide between Wollal and Pardu Homesteads and render motor travel along the main north-south road very difficult. In Northwest Basin similar sand-ridges rest on top of Kennedy Range (Plate xix,

fig. 1) and they form high barriers to the good grazing country west of Exmouth Gulf.

2. Sea-level plains, including Roebuck, Anna and other Plains, at sea-level or within 5 feet of high water mark.—These are formed of silt and are saliferous and full of Recent marine shells. In the country north of Broome, dead cajiput trees, on and behind these plains, signify that the land is now sinking. The plains extend at times as much as 30 miles inland from the coast, fringed and backed by "pindan sands." The sea-level plains appear to be, next to unconsolidated sand-dunes, the most recent formation of southern Kimberley Division. The following Post-Tertiary species have been identified by Mr. W. S. Dun from collections by me near Coolmakop well, 10 miles southwest of Male Station, on the southeast edge of Roebuck Plains, 30 miles southeast of Broome:

Post-Tertiary species collected on Roebuck Plains.

Arenlaria venuste Dunke.
Cassidula angulifera Petit.
Cerithoidea obtusa Wood.
Cerithoidea kieneri.
Ellobium auris-judie Linn.
Melampus flexuosus (?).
Plectotrema sp. (?).
Arenlaria optima.
Melaraphe scabra Linn.
Nerita albicilla Linn.
Pyrazus fluviatilis.
Corbula crassa Hinds.
Arca granosa Linn., var. *cuniata* Reeve.
Pupoides pacificus Pfeiffer.
Succinea operta Cox.
Succinea scalarina Pfeiffer.

3. Consolidated sand-dunes.—Not necessarily older in every instance than the unconsolidated sand-dunes, yet consolidated to the consistency of sandstone; sometimes cut by the sea waves and forming vertical sections 10 to 70 feet high on the coast from Broome southward. The cross-bedding and typical dune formation are illustrated in Plate xvi, fig. 2.

4. "Coquina" or shell rock.—Deposits of shells, 20 feet in thickness, extending to that height above high water mark near Kamelin Pool, and lower deposits of shell rock on the coast at Port Hedland and Broome.

5. Raised sea-beaches.—These consist of sandstone, limestone or comminuted masses of shells and sand-grains. Raised beaches have been seen at frequent intervals from Port Hedland to Lagrange, and they sometimes rise 50 feet above tide level. In topography they take the form of beach-like belts sometimes paralleling the coast for many miles. The surface of these beds is frequently considerably hardened and the outcrop has a concentric pseudo-folded appearance. The best exposures were seen 2 miles southwest of the southwest end of Ninety Mile Beach on Pardu Station, where a ragged limestone outcrop, 50 feet high, composed of shelly calcareous sandstone, forms the coast for a mile or two. At Port Hedland similar outcrops rise 10 to 15 feet above high tide.

If the dead trees surrounding the sea-level plains north of Broome indicate a sinking of that part of the coast at the present time, the raised beaches indicate a recent rising of the coasts in the area from Lagrange southward. The pivot appears to be not far from Broome.

6. A zone of red soil.—This has been seen in a few localities near Broome and is exposed a few feet in thickness underneath the "'petrified" coastal sand-dunes at Cape Villaret. The red soils are Recent or Quaternary in age.

7. "Pindan sands."—Practically all of the country round Broome, with the exception of the sea-level plains and the small areas of rock, is known as the "pindan sands." Such areas consist of level to gently rising unconsolidated sands, often rising to several hundred feet above sea-level at distances from the coast, and in general sloping upwards against older formations. The "pindan sands" are generally covered with a thick growth of shrubs or low trees of many varieties, known collectively as "pindan." These sands are probably of various ages from Permo-Carboniferous to Recent, and can not be differentiated until enough wells are sunk in them so that fossils shall have been found and determined at widespread localities.

The "pindan sands" cover nearly the whole of the peninsula west of King Sound, most of the country east of Broome, north and south of the Derby road, and extend southeast from Broome from the inner edge of Roebuck Plains to a distance of over 100 miles and beyond that until they merge with the sand-ridge country of the semi-desert; and they also occupy the inter-sand-ridge spaces. Most of the country from Broome south to Port Hedland that is not a sea-level plain is a part of the "pindan sands"; and in fact the term is doubtless applicable much farther south, except that the word "pindan" is apparently limited to the North.

The "Cape Range" formation.

The most unexpected discovery of any relative to the Tertiary system was in the "Cape Range," extending south from Northwest Cape, where white limestones and interstratified chalky beds form a great anticline rising from below sea-level on the west side of Exmouth Gulf to a height of over 1,000 feet in the centre of the Range (Fig. 4), intersected by deep gorges extending back miles into it. Some beds of the chalky material are full of foraminifera, as yet unidentified, and only surmised to be of Tertiary age.* The east dips vary from nil on top of the Range to 8 degrees on the lower east flank (Plate xvii, fig. 2). Far up a gorge in the Range, at a point 15 miles south of Northwest Cape, I saw the dips flatten out and then dip toward the west at an angle of 2 degrees; but the gorge was not followed farther west. Rocks are also reported to dip sea-wards at Pt. Cloates, 75 miles south of Northwest Cape, on the west side of the Range.

I infer that the Range is an anticline, because, firstly, west dips of 2 degrees were actually observed along a line not far from the centre of the mountain range; and secondly, if the Range were a monocline it would imply a shore line to the west, which has not been proved or even suspected. East of the anticline of Cape Range other anticlines were found, one of which, on Giralia Station, 20 miles east of Cape Range, has a height of at least 300 feet and a breadth of 10 miles.

For the strata that comprise these anticlines and form the surface between them, I suggest the name "Cape Range" formation. The foraminifera have not yet been determined, but it seems probable that they will show a Tertiary age.

* *Note*, 29th March, 1925.—Word has just been received from Professor Sir T. W. E. David that Mr. F. Chapman states emphatically that these foraminifera are Oligocene types of *Lepidocyclina* and *Cycloclypeus*. The above is therefore an important discovery of raised and flexed Oligocene limestones in Western Australia.—Ed.

Large areas along the coast and for some miles back from it between Northwest Cape and Hamelin Pool may be part of the same formation.

Country east of Onslow.

An interesting section, 7 miles in breadth, of some of the very old rocks, exists in the interval from about 35 to about 42 miles east from Onslow. More or less continuous outcrops were passed on a northeast-southwest traverse, all dipping at an average angle of 20 degrees in a direction S. 60° E. Thus, the strata, if not duplicated by unseen faults, appear to be perhaps 13,000 feet in total thickness. They consist of rather uniform, hard, light gray, thick-bedded quartzites, with some medium-grained sandstone and traces of softer white material below the hard surface.

Although this belt of outcrops appears to lie on the strike of the Mosquito Creek beds (pre-Cambrian) mapped less than 100 miles to the south, the rocks are perhaps similar in character to some of the Permo-Carboniferous rocks when surface-hardened. The locality was not observed to be cut by quartz veins or by granite, like the Mosquito Creek beds seen elsewhere; and the only intrusion noticed was a large dyke of basalt, apparently occupying the centre of an anticlinal fold just west of Peedamullah Homestead.

Similar gray quartzites of similarly great thickness, seen in the area between Nanutarra and Uaroo Homesteads, south of Ashburton River, are underlain by at least 2,000 feet of schists. The formation south of Nanutarra is folded into several great anticlines, in the centre of which valleys have been eroded; but in that area the quartzites and schists are intruded by innumerable quartz veins, granites and gneisses, so that here, as in the De Grey River country, certain granites can be proved younger than certain sedimentaries.

Conclusion.

The matters discussed in this paper constitute merely a few of the problems existing in the northwest of Western Australia. Other problems are (1) Climatic factors in geological history, (2) Number of glacial periods, (3) Unity or multiplicity of the northwestern laterites, (4) Question of faulting on the east side of Northwest Basin, (5) Ages of folding in Kimberley Division, east side of Northwest Basin and west edge of Northwest Basin, (6) Water problem in Desert Basin, (7) Origin of certain saline waters, (8) Climatic factors in human history, and many others that apply to that part of the Commonwealth. A vast field exists for geological work; the importance of the work to the future welfare of the State and the Commonwealth is very great, in addition to the benefits to be derived by science from such investigations.

In conclusion I want to express my obligation to Mr. A. E. Broué for permission to make the facts and theories in this paper available to geologists. I also wish to thank Prof. Sir T. W. Edgeworth David for valuable advice on stratigraphical matters, Mr. W. S. Dun for final determination of fossil species, and Mr. A. Gibb Maitland for counsel and general advice as to methods of approaching the field and problems.

EXPLANATION OF PLATES XVI—XIX.

Plate xvi.

1. Typical sand-dunes near Broome.
2. Wave cut cliff of consolidated sand-dunes at Cape Villaret.
3. Mt. Phire—an outlying table-land of Jurassic age.

Plate xvii.

1. Formations constituting Mt. Phire.
2. East dips in Cape Range, west of Exmouth Gulf.

Plate xviii.

1. Surface hardening in sandstone of Jurassic age at Cape Villaret.
2. Sandstone of probable Jurassic age, Gantheaume Pt.

Plate xix.

1. View of top of Kennedy Range, site of Merlingleigh Homestead.
2. Lyons Conglomerate (tillite) east of Gascoyne Junction.
3. Dips on east flank of dome on southwest Williambury Station, Northwest Basin.